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EFFECT OF MANUAL METAL ARC WELDING PARAMETERS ON CORROSION BEHAVIOUR OF STAINLESS STEEL

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ABSTRACT

In this work, effect of welding electrode, welding current and corrosion media on corrosion behaviour of three kinds of stainless steel (AISI 304, AISI 316 and AISI 410) was investigated. Welding was performed by manual metal arc welding process using three types of welding electrode (E308L, E316L and E310). Corrosion behaviour of the welded joints was examined in two chloride mediums (3.5%NaCl and 3.5%KCl). The results showed that welding electrodes E316L and E310, which contain Mo and Ni respectively, increase corrosion resistance in of the weldment. The increment in heat input by increasing welding current caused reduction in corrosion resistance by facilitating carbon diffusion and formation of chromium carbides in the weld area. It was also found that corrosion rate of 3.5% NaCl was more aggressive than 3.5% KCl.

Key words: Corrosion behaviour; Stainless steel; welding electrodes; chloride media, alloying elements.

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1. INTRODUCTION

Stainless steels are important class of engineering materials which have been used widely in different environments and industries [1]. Their excellent properties including, corrosion and wear resistance, high impact and tensile strength have found a variety of applications in many executive fields that require a boosting of these properties, such as pressure boilers, evaporator tubes and pressure vessels [2]. Fabrication of stainless steels in different shapes and sizes are frequently made by welding. Fusion welding is the most versatile process for joining stainless steels [3]. However, the high temperature required for fusion can cause several metallurgical changes that consequently affect the weld joint quality [4]. Therefore, the right selection of welding parameters such as welding current and time can increase the mechanical properties of the welded parts and improve the corrosion resistance [5, 6]. For example, corrosion resistance of austenitic stainless steel in chloride media increases with increasing welding heat input by raising the electrode potential values. The using of low heat input takes longer welding time that exposes the metal for prolong heating during welding and causes precipitation of carbon and formation of chromium carbide [7]. This consequently reduces chromium in the matrix and results in loss of metal passivity and accelerates the corrosion attack by chloride ion [4]. Pitting corrosion of austenitic stainless steel is also directly affected by welding current. High welding current increases resistance of stainless steel against pitting. Slow cooling rate resulted from high welding heat input raises the critical pitting temperature and enhances the pitting resistance equivalent number [5]. However, some studies reported that high heat input combined with slow cooling rate could produce more delta ferrite in the microstructure that causes local segregation of chromium carbides and reduction in chromium content. This local change in composition leads to reduction in corrosion resistance [8].

Alloy composition can also determine the properties of the weld. Mo and Ni can enhance pitting corrosion resistance and reduce corrosion rate [9]. Mo enhances the corrosion resistance of passive film, improves the repassivation characteristics and decreases the active rate of dissolution inside the pits of bare metal [10]. Ni also influences the corrosion resistance of steels by increasing the passive film [11]. The addition of Ni in particular amount improves the corrosion resistance of weathering steel, which shows its best atmospheric corrosion resistance at 3% of Ni [12]. 1-3% extra content of Ni in low alloy steel highly increases the corrosion resistance in dry/wet cyclic corrosion test in chloride media [13]. Welding electrodes usually contain alloying elements. During welding, the alloying elements feed the weld metal with certain elements that enhance the properties of the weld including corrosion properties. This work studied the impact of alloying elements that included in the welding electrodes on corrosion resistance of the of AISI (304, 316 and 410) stainless steel weldments in a chloride media[16,17]. The effect of welding current and corrosion media on corrosion behaviour of the weldments was also investigated.

2. EXPERIMENTAL WORK

2.1. Materials

Three types of stainless steel sheets (AISI 304, AISI 316 and AISI 410) with dimensions of 100×50mm×2 mm were used as base metals (BM) in this research. All the stainless steel sheets were received in mill annealed condition. Their chemical composition (Table 1) was analysed at the Central Institution for Measuring and Quality Control/Iraq. Welding operation was carried out using three welding electrode types (E 308L, E 316L and E 310) with diameter of 3.25 mm.

Table 1. Chemical composition (wt%) of stainless steel base metals. (The remained is Fe).

Stainless steel type	Elements							
	C	Cr	Ni	Mo	Si	Mn	P	S
AISI 304	0.06	19.8	9.55	-	0.41	1.35	0.013	0.002
AISI 304 (Std)	0.08	18-20	8-10.5	-	1	2	0.045	0.03
AISI 316	0.06	16.3	12.5	2.1	0.62	1.53	0.035	0.002
AISI 316 (Std)	0.08	16-18	10-14	2-3	1	2	0.045	0.03
AISI 410	o.12	11.7	0.38	-	0.43	0.94	0.028	0.007
AISI 410 (Std)	0.15	11.5-13.5	-	-	1	1	-	-

*(Std) = Nominal chemical composition according to ASTM standard.

2.2. Welding Procedure

Welding was performed using manual metal arc welding (MMAW) process using butt joint. Three welding currents namely, 100 A, 150 A and 200 A were utilized in this study. The weldments were subjected to visual inspection to assure that they are free of welding defects such undercut, porosity and lack of penetration.

2.3. Corrosion test

For corrosion test, the weldments were cut in into pieces with dimensions of 10×10×2 mm in the weld region. Corrosion tests were performed at room temperature using Wenking M-Lap potentiostat device. The electrodes material were Ag and Pt and the duration of the test was 14 minutes. Two corrosive media were used (3.5% Sodium chloride and 3.5% Calcium chlorides). Electrochemical corrosion measurement was used because many types of corrosion occur via electrochemical reactions at the interface between an electrolyte solution and the metal [1, 14]. The identifications of corrosion type and distribution of alloying elements were performed using a scanning electron microscope (SEM) and energy dispersive X-ray (EDS). Corrosion rate was calculated using equation (1).

$CR = K_1 \frac{i_{cor}}{\rho}$ EW ….(1) [15]

Where, CR= Corrosion rate (mpy), K_1 = 0.1288, i_{cor} = Corrosion current density (μA/cm^2), ρ = Density (gm/cm$^{3)}$, EW= Equivalent weight.

3. RESULTS AND DISCUSSION

3.1. Effect of welding electrode on the corrosion rate

3.1.1. AISI 304 stainless steel

E 308L, E 316L and E 310 electrodes were used to weld AISI 304 stainless steel at constant welding current (100 A). The weldments were subjected to corrosion test using 3.5%NaCl. Using Tafel plot (Figure 1), it was found that welding with E310 showed lowest corrosion rate (Table 2) with 4.93 mpy. The low corrosion rate value is probably due to the relatively high Ni content included in E310 that provides the weld area with more Ni and raises the size of passive film, which consequently decreases the corrosion rate [13].

Table 2. Corrosion rate as a function of electrode type for AISI 304 base metal

Electrode type	Corrosion rate (mpy)
E310	4.93
E316L	13.12
E308L	16.78

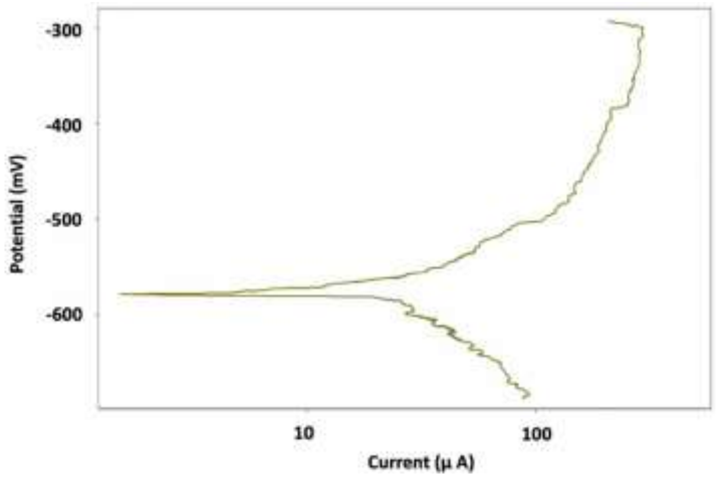


Figure 1. Tafel plot for AISI 304 stainless steel welded with E310

3.1.2. AISI 316 stainless steel

The base metal of AISI 316 was also welded with E 308L, E 316L and E 310 electrodes and constant welding current of 100 A. The corrosion test was performed using 3.5% NaCl as a corrosive media. Welding with E316 showed a very low corrosion current as shown in Tafel plot (Figure 2) and lowest corrosion rate value of 1.89 mpy as can be seen in Table 3. The very low corrosion rate for the AISI 316 weld could be due to the effect of Mo alloying element that included in the welding electrodes and the base metal itself. The high molybdenum in the E316L improves the corrosion resistance of the passive film, increases the repassivation features and declines the active level of dissolution inside the pits of the base metal [9, 10].

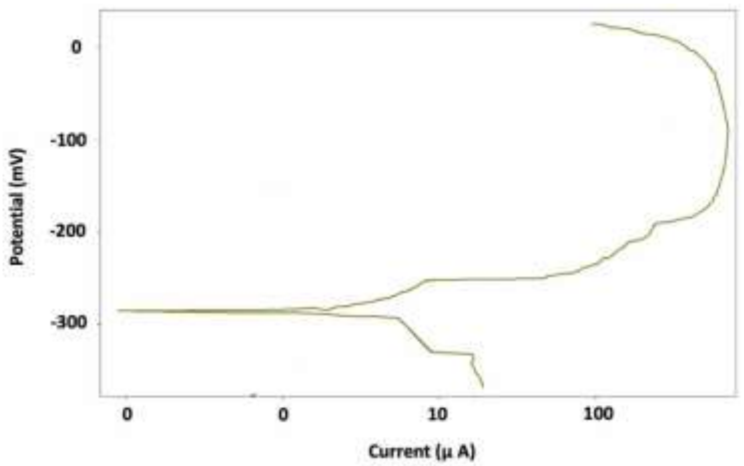


Figure 2. Tafel plot for AISI 316 welded with E316L

Table 3. Corrosion rate as a function of electrode type for AISI 316 weldments

Electrode type	Corrosion rate (mpy)
E308L	14.38
E316L	1.89
E310	18.59

3.1.3. AISI 410 stainless steel

Using the same welding and test conditions (100A and 3.5% NaCl), the results (Table 4) showed that highest corrosion rate of 21.38 mpy was obtained with E310 welding electrode. While, E316L gave the best corrosion resistance of 6.97 mpy, which can be expected from low corrosion current attained with this electrode as can be seen in Tafel plot (Figure 3). The results of this alloy can be explained in terms of the effect of high carbon content (0.12%) in the base metal and Mo in the electrode that led to decrease in corrosion sensitivity and prevent the weld sensitization. Mo picks the C and prevents the formation of chromium carbides and reduction of Cr in the matrix. [10].

Table 4. Corrosion rate as a function of electrode type for AISI 410 weldments

Electrode type	Corrosion rate (mpy)
E308L	13.80
E316L	6.97
E310	21.38

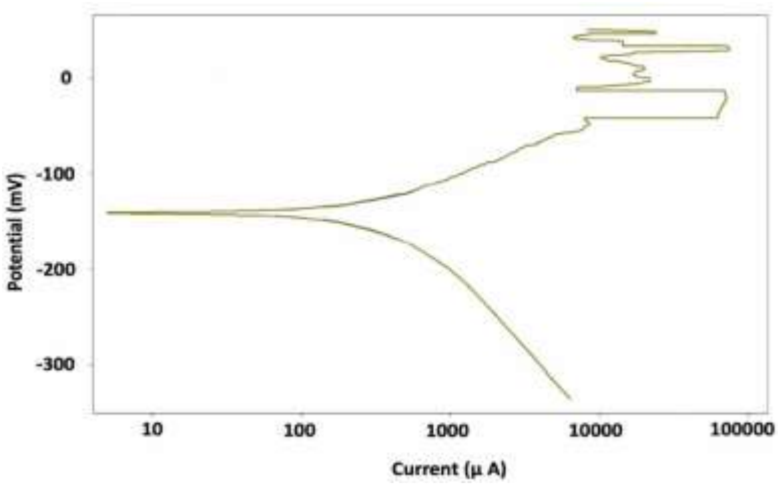


Figure 3. Tafel plot for AISI 410 welded with E316L

3.2. Effect of welding current on corrosion rate

Three welding currents namely 100, 150 and 200 A were used to study the influence of welding current on corrosion rate of the weldments. AISI 316 was used as a base metal and E316L as a welding electrode because the highest corrosion resistance was achieved with these welding conditions. The test was performed using 3.5% NaCl as corrosion media. It was found that corrosion current (Figures 4 and 5) and consequently corrosion rate increase with increasing welding current. With 100A, corrosion rate was low as 1.89 mpy and increases to 7.97 mpy and 13.88 mpy with 150A and 200A respectively. High corrosion rate increases the pitting size as can be clearly seen in Figure 6 (a & b). The significant growth in pitting size with higher welding current (200 A), could be attributed to the formation of chromium carbides and consequently depletion of chromium in the matrix as a result of high heat input [8]. Carbide formation was verified by EDS analysis (Figure 7 (a & b)) where higher carbon percentage was obtained with 200A than 100 A. High welding current raises the possibility of carbon diffusion in the weld region. High percentage of carbon tends to reduce the Cr content through formation of chromium carbides and lowers the corrosion resistance.

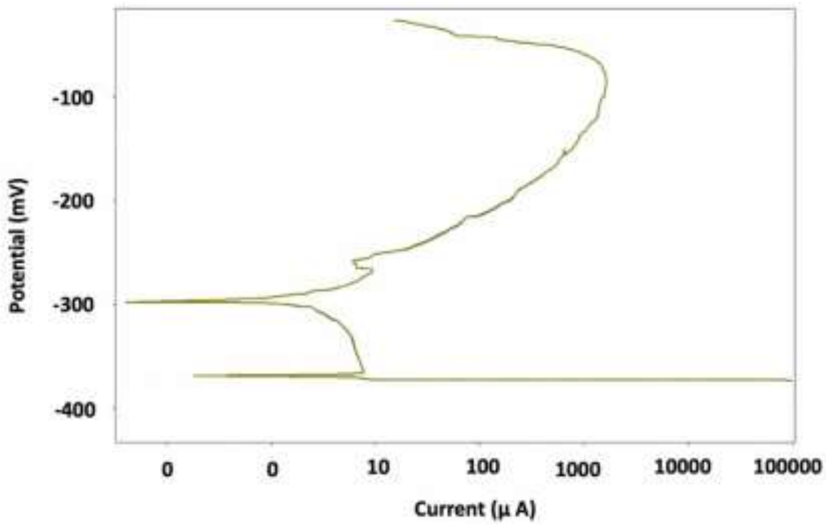


Figure 4. Tafel plot for AISI 316 stainless steel welded with 150 A welding current and E316L.

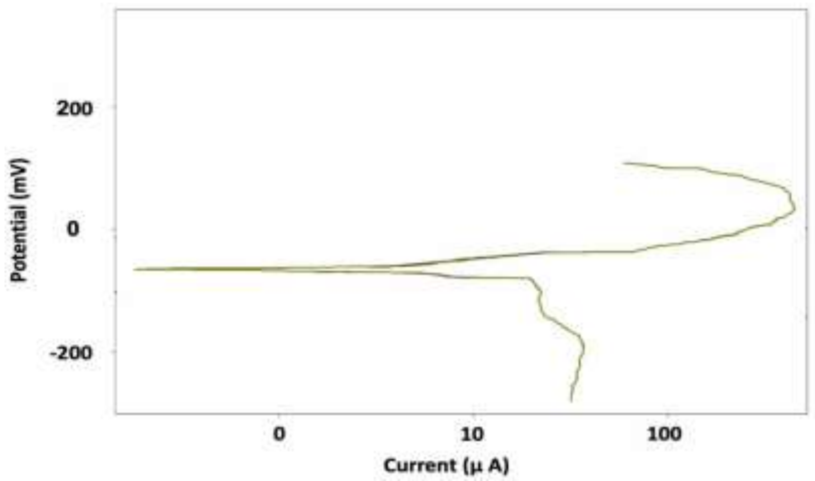


Figure 5. Tafel plot for AISI 316 stainless steel welded with 200 A welding current and E316L.

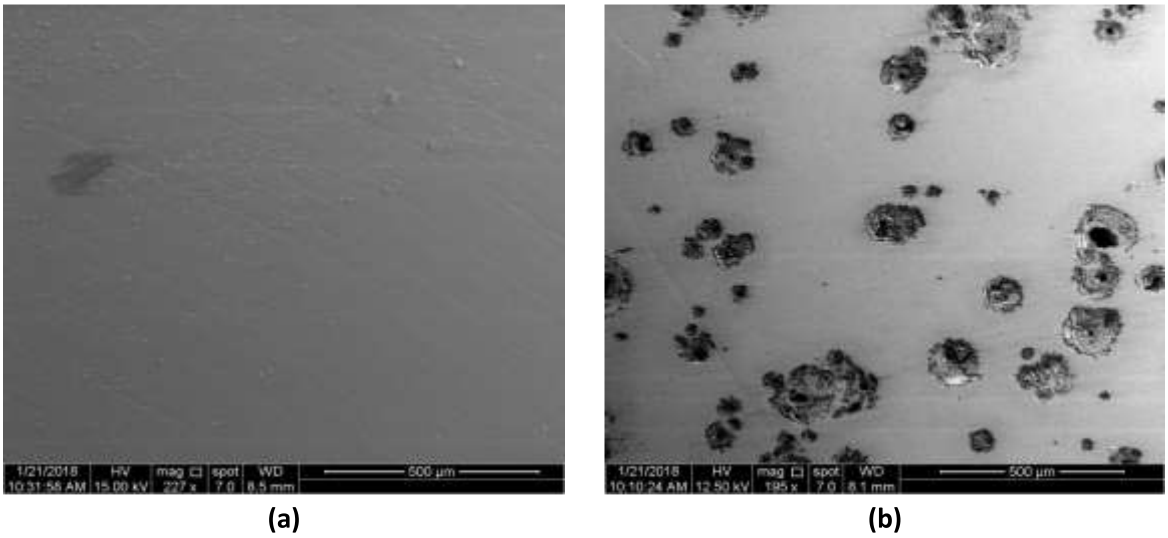
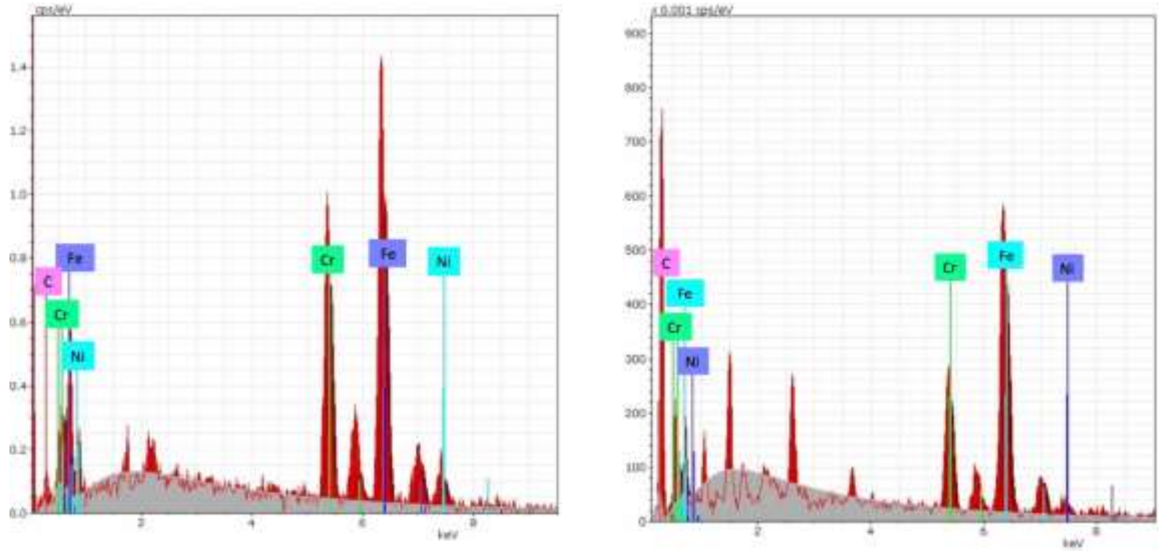


Figure 6. SEM micrograph of AISI 316L weldment welded with (a) 100A (b) 200A.



(a) (b)

Figure 7. EDS analysis of AISI 316L weldment welded with (a) 100 A (b) 200 A.

3.3. Effect of corrosion media on corrosion rate

Two corrosive mediums, namely 3.5% NaCl and KCl were used to investigate the impact of corrosion media on corrosion rate. The best conditions (the lowest corrosion rate) of the three welding alloys were used as can be seen in Table 5. It can be noticed that the all readings in 3.5% KCl were lower than 3.5% NaCl due to the higher PH of NaCl than KCl. This difference in PH led to breakdown of the protective layers and the corrosion became easier to take place [18].

Table 5. Effect of corrosion media on corrosion rate at 100A welding current

Welding condition	Corrosion media	
	3.5% NaCl	**3.5% KCl**
AISI 304,E308L,100A.	16.78 mpy	0.227 mpy.
AISI 316,E316L,100A.	1.89 mpy	0.080 mpy.
AISI 410,E316L,100A.	6.97 mpy	0.410 mpy.

4. CONCLUSIONS

- Welding electrodes influence the corrosion behaviour of the weldment by providing weld metal with certain alloying elements such as Ni and Mo that enhances corrosion resistance.
- Corrosion rate increases with increasing welding current.
- High welding current raises the possibility of carbide formation and consequently reduces the corrosion resistance.
- Big size of pits was observed with 200 A comparing to 100 A.
- 3.5% NaCl is more aggressive than 3.5% KCl as corrosive media.

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